

**Diaphragm pump**

Background of the invention

5 This application is a continuation-in-part of application Serial No. 10/600,299 filed June 20, 2003, now pending, which is a continuation-in-part of application Serial No. 10/383,954, filed March 7, 2003, now pending.

10 The present invention relates to a diaphragm pump as disclosed in copending application Serial No. 10/383,954, but with a variable stroke volume, this being achieved by means of a metering device in the form of a metering head, and to the use of this diaphragm pump as a controllable valve or as controllable multi-way distributor valves or multi-component distributor valves.

15 Copending application Serial No. 10/383,954, the disclosure of which is incorporated herein by reference, discloses a diaphragm pump with a multipart pump body, said pump comprising at least of three rigid plates and at least two elastic diaphragms arranged between these plates, the plates forming, in particular, one pumping chamber and at least two shut-off chambers, each with an inlet and an outlet orifice  
20 for the feed material, and the pumping chambers and shut-off chambers forming, together with an inlet duct, connecting ducts and an outlet duct, a passage duct, the pumping chamber and the shut-off chambers being divided by the diaphragms in each case into a product space and a control space, and the control spaces having control lines which are connected to a control unit.

25 It was shown, when the diaphragm pump according to copending application Serial No. 10/383,954 was used, that this does not always satisfy all requirements, particularly when substances of different density are to be metered accurately or the diaphragm pump is to be used as a multi-way valve.

30 The object of the present invention is, therefore, to provide a diaphragm pump which is an improvement over the diaphragm pump of application Serial No. 10/383,954

and which, highly miniaturized, conveys small volume quantities per unit of time and possesses high short-term metering accuracy. The improved pump has a good intake behavior and conveys against pressure, so that even in the non-flooded state of the pump head, conveyance against pressure and a part-stroke operating mode are possible, but a sampling of the feed material is also possible at any time.

#### Summary of the invention

This object is achieved by an electropneumatically driven pump head as illustrated in Fig. 2 which is constructed in a modular lamella-like manner and which, multi-part, is comprised of at least three rigid plates (lamellae), said at least three rigid plates comprising two outer plates (201, 205) and one inner plate (203) and at least two elastic diaphragms (204, 202) arranged between these plates, the inner plate (203) and at least one outer plate (205) forming at least one pumping chamber (211) and the inner plate and the other of said at least two outer plates (201) forming at least two shut-off chambers (210, 212), particularly in the geometry of a spherical segment, a spherical zone, a cylinder or a truncated cone, each with an inlet orifice (240) and an outlet orifice (241) for the feed material, and the pumping chamber (211) and the shut-off chambers (210, 212) forming, together with an inlet duct (207), the connecting ducts (208) and (209) and an outlet duct (206), a passage duct, the pumping chamber (211) and the shut-off chambers (210, 212) being separated by the diaphragms (204, 202) in each case into a product space (230, 231, 232) and a control space (220, 221, 222), and the control spaces (220, 221, 222) having control lines (119, 120, 121) which are connected to a control unit (100, 115), and wherein the control space of the pumping chamber is enlarged sufficiently to accommodate an axially movable disc (1001), having an extended rod (1002) attached on one side, inserted into said control space, so that the rod attached on one side of the movable disc is extended through the outside plate and projects outside the metering head, and can be adjusted (1003) from outside the pump, and, as a result, the disc (1001) located in the control space is movable axially to reduce or increase the range of possible diaphragm travel in the pumping chamber, so that the metered liquid volume

per conveying stroke can be varied and the pump operated in a part-stroke operating mode, without the dead-space volume in the product space being increased.

5 Preferably, the outer plate forming the pumping chamber/control space within which the axially movable disc (1001) is inserted is of stronger or thicker design than the other plates, so as to accommodate said axially movable disc.

The invention relates, furthermore, to a diaphragm pump as illustrated in Fig. 1, with a multi-part pump head which is comprised of at least three rigid plates (lamellae), said at least three rigid plates comprising two outside plates (201, 205) and an inner plate (203) and at least two elastic diaphragms (204, 202) arranged between these plates (201, 203, 205), the inner plate (203) and one of said outside plates (205) forming at least one pumping chamber (211) and said inner plate and the other outside plate (201) forming at least two shut-off chambers (210, 212), particularly in the geometry of a spherical segment, a spherical zone, a cylinder or a truncated cone, each with an inlet orifice (240) and an outlet orifice (241) for the feed material, and the pumping chamber (211) and the shut-off chambers (210, 212) forming, together with an inlet duct (207), the connecting ducts (208) and (209) and an outlet duct (206), a passage duct; the pumping chamber (211) and the shut-off chambers (210, 212) being separated by the diaphragms (204, 202) in each case into a product space (230, 231, 232) and a control space (220, 221, 222), and the control spaces (220, 221, 222) having control lines (119, 120, 121) which are connected to a control unit (100, 115), the control space of the pumping chamber being sufficiently enlarged to accommodate an axially movable disc (1001), having a rod (1002) attached on one side, inserted in the control space, so that the rod attached on one side of the movable disc extends through the outer plate (205) and projects outside the metering head and can be adjusted (1003) from outside the pump, and, as a result, the disc (1001) located in the control space can be moved axially to reduce or increase the possible diaphragm travel in the pumping chamber, so that the metered liquid volume per conveying stroke can be varied and the pump operated in a part-stroke operating mode, without the dead-space volume in the product space being increased, and wherein said diaphragm pump has a decentral electropneumatic control unit for

driving the pump head. Preferably, the outer plate (205) forming the pumping chamber/control space within which the axially movable disc (1001) is inserted is of stronger or thicker design than the other plates, so as to accommodate the movable disc (1001).

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#### Detailed description

The diaphragm pump according to the invention, comprised of the pump head according to the invention and a decentral control unit, makes it possible to convey small volume quantities per unit of time, has high short-term metering accuracy, exhibits a good intake behavior, is capable of conveying against pressure even in a non-flooded state of the pump head and also is capable of part-stroke operating mode at any time. The diaphragm pump according to the invention makes it possible, in the most diverse possible applications, to convey liquids with a viscosity range of 0.001 Pas to 10 Pas, preferably 0.001 to 5 Pas and, particularly preferably, liquids with a viscosity of 0.001 to 2 Pas.

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The disc (1001) movable in the axial direction in the control space of the pumping chamber (211) by rotation of the threaded rod makes it possible to reduce or increase the maximum stroke travel of the conveying pump diaphragm (204), so that pumping in a part-stroke operating mode is possible. In addition, a reduction in the diaphragm load occurs, so that, depending on the elastic material used, the permanent deformation arising is compensated by a variation in the diaphragm stroke travel.

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The axially movable disc (1001) within the control space of the pumping chamber varies the possible diaphragm movement in the axial direction in the range of from 1% to 100% of the structurally largest stroke travel, the limitation preferably being from 10% to 100% and, particularly preferably, the limitation being in a range of 20% to 100% stroke travel, without the dead-space volume of the pumping chamber being increased.

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The rod (1002) allows the adjustment of the movable disc (1001) from outside of the diaphragm pump. The adjustment can be for example motoric, hydraulic, pneumatic,

a piezo-operated adjustment or a simple manual adjustment. Anyway the adjustment is done by rotary motion. The rod (1002) may be a threaded rod or non-threaded rod.

5 In a preferred embodiment of the invention, the axial disc adjustment within the control space of the pumping chamber may take place at the adjusting wheel (1003), even automatically or by remote control when an electrically operated motor or a hydraulic or pneumatic drive is mounted.

10 An automatically adjustable part-stroke of the pump diaphragm forms an actuator, so that, in combination with a throughflow sensor, throughflow regulation can be set up.

15 The set delivery rate of the pump may be checked, for example, by means of a balance. If deviations from the predetermined metering rate occur, the balance transmits a signal to the monitoring controller, and the controller transmits a control signal to the drive which can move, in the axial direction, the disc (1001) fastened to the output shaft in the pump control space and thus adjust the pump-stroke volume, in order to make a correction of the pump delivery rate.

20 The axially movable disc (1001) inserted in the control space may have different shapes on the side facing towards the diaphragm. The disc may be in the shape of a planar cylindrical disc (Fig. 2a), of an obtuse cone (Fig. 2b) or of a spherical segment as shown in Fig. 2 (1001). In particular, a shape adapted to the product-side depression of the pumping chamber has advantages to the effect that, in the case of a maximum adjustment of the movable disc, the supplying and discharging connecting ducts (208,209) of the pumping chamber are closed.

25 The axially movable disc (1001) is provided with orifices or bores (1007) and, if appropriate, is additionally provided, on the side facing away from the diaphragm, with a concentrically raised ring (1008), so that the pneumatic connection cannot be closed in the case of a complete return of the disc.

As compared with the diaphragm pump according to copending application Serial No. 10/383,954, the diaphragm pump improved according to the present invention has a simpler setting or variation of the metering capacity and of the volume flows to be conveyed. The use of the part-stroke operating mode applies to pumping chambers  
5 with a stroke volume of from greater than 10  $\mu\text{l}$ /stroke up to 100,000  $\mu\text{l}$ /stroke. In light of different corrosion requirements in the chemical industry, the diaphragm pump according to the invention can be produced cost-effectively from various corrosion resistant materials. Repair and maintenance are simple and inexpensive.

10 The design of the control or drive technology of the diaphragm pump according to the invention has no influence on the pump-head size and the possibility of integration in a miniaturized test installation set-up. The diaphragm pump according to the invention can be constructed in a modular manner, so that, by appropriate additions or the exchange of module parts, an easy adaptation of its functions to the  
15 feed material can be carried out. The change in the metering capacity takes place, without the displacement travel of the diaphragm or of the movable disc (1001) in the pump head increasing the dead volume, so that the liquid volume taken-in is displaced out of the pump head completely at any time.

20 In a further preferred embodiment of the diaphragm pump or of the pump head, by means of a pressure regulator preceding the control unit, the control pressure on the diaphragm in all the control spaces is at least 0.1 bar higher than the prevailing pressure at the outlet duct of the pump head, preferably the control pressure is at least 0.5 bar higher and, particularly preferably, the control pressure is 1 bar higher than  
25 the pressure to be expected at the outlet duct.

The higher differential pressure between the outlet duct (206) and the control-side pressure ensures the leak-tight closing of the respective inlet orifices in the chambers by means of the diaphragm.

The diaphragms (202, 204) are preferably formed of an elastic material, in particular of an elastomer, silicone, Viton<sup>®</sup> fluororoelastomer, Teflon<sup>®</sup> polytetrafluoroethylene or a rubber.

5 Preferred diaphragms are comprised of an elastic laminate of at least two interconnected material layers with different moduli of elasticity. The individual layers are adhesively bonded or connected to one another. In principle, this feature may also be applied to the diaphragm pump of copending application Serial No. 10/383,954.

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Thus, for example, a thin Teflon<sup>®</sup> film may be connected to a highly elastic rubber, in order to increase the required return forces of the diaphragm laminate and thus reshape into the original state, with insignificant auxiliary energy, a diaphragm laminate which is deformed during the displacement of liquid.

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A preferred version of the diaphragms used is one wherein thin elastic films are partially chambered and the structural parts or the components for diaphragm chambering are comprised of corrosion-resistant materials and chamber up to 30% of the product-touched diaphragm surface, preferably chamber up to 65% and particularly preferably up to 80% of the product-touched diaphragm surface.

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The use of a chambered diaphragm reduces the plastic deformation occurring under load, so that, under high mechanical load, the plastic or permanent diaphragm deformation is extremely low or has a negligible influence on metering accuracy. The two plate-shaped diaphragm chamber elements in Fig. 3 (1100, 1101) are preferably disc-shaped and on the outer diameter have a concentric raised ring (1102, 1103) formed towards the diaphragm side, so that large diaphragm-surface fractions are clamped and are not subject to any deformation force or stretching force in the chambered region.

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Preferably, chamber elements are used in the case of a diaphragm diameter larger than 10 mm to smaller than 1000 mm, preferably in a diameter range of larger than 20 mm to smaller than 800 mm and, particularly preferably, in a diameter range of larger than 25 mm to smaller than 200 mm.

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A preferred version of the diaphragm pump or of the pump head, characterized in that the pumping chamber and the shut-off chambers are provided with associated chambered diaphragms, is particularly advantageous.

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A preferred version of the diaphragm pump or of the pump head, characterized in that only the pumping chamber is provided with a chambered diaphragm, is particularly advantageous (Fig. 3).

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If large surface fractions of the diaphragm are chambered, the product-side surface (1104) of the diaphragm chamber component may be coated with an elastic layer or film in order to close supplying and/or discharging connecting ducts of the pumping chamber in a leak-tight manner (see Fig. 3).

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A preferred version of the diaphragm pump or of the pump head, in which a plurality of shut-off chambers have a common diaphragm, is particularly advantageous (Fig. 1).

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A preferred version of the diaphragm pump or of the pump head is characterized in that the pump head is comprised of at least three plates and the pumping and shut-off chambers are formed by depressions in the plates (Fig. 2).

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In a particularly preferred form of construction, the diaphragm pump or the pump head is comprised of at least three plates and the pumping and shut-off chambers (210, 211, 212) are formed by depressions in the middle plate.

Another particularly preferred form of the diaphragm pump or of the pump head is characterized in that it is comprised of at least three plates and the pumping and shut-off chambers are formed by depressions (210, 211, 212) in the outer plates.

In a particularly preferred embodiment of the diaphragm pump or of the pump head, a groove (213), which connects the vertex of the pumping-chamber depression to the outlet orifice of the pumping chamber, is located at least in the product space of the pumping chamber (231).

In a preferred embodiment, those walls of the control spaces which are located opposite the diaphragm, but at least in the pumping chamber, have a compensating volume in the form of a sheet-like depression. As a result, when a vacuum prevails in the control space, the diaphragm becomes deformed and can in extreme situations fit snugly together with the adjustable disc which is the wall of the control space. At the same time, an enlargement of the respective product space takes place (illustrated by way of example in Fig. 1 in the product space of the shut-off chamber (212)).

In a particularly preferred embodiment of the diaphragm pump or of the pump head, the compensating volume is at most 100% of the respective associated product-space volume, preferably the compensating volume is at most 20%, and, particularly preferably, the compensating volume is at most 10% of the product-space volume.

The compensating volume describes the space into which the diaphragm present is deformed when a vacuum prevails. If the compensating volume is increased and equipped with an adjustable disc (1001), the compensating volume has no influence on the product-side depression volume of the pumping chamber due to the axial adjustment of the movable disc (1001).

Typically, the product spaces of the shut-off chambers (210, 212) are designed to be smaller than the product space of the pumping chamber (211).

In a particularly preferred embodiment of the diaphragm pump or of the pump head, the shut-off-chamber volume is 1% to 50% of the product-side pumping-chamber volume, preferably 1% to 30% and particularly preferably 1% to 15%. In principle,

this feature may also be applied to a diaphragm pump according to copending application Serial No. 10/383,954.

5       The center-to-center distance of the respectively adjacent inlet and outlet of each pumping or shut-off chamber is two to ten times the largest hydraulic diameter of the respective inlet orifice (240) or outlet orifice (241), preferably the center-to-center distance is two to five times and particularly preferably twice to three times the hydraulic diameter of the largest of said orifices.

10       The defined center-to-center distance is an important functional dimension of the chambers. It ensures a leak-tight closing of the supplying and discharging ducts or orifices and increases the reproducibility of the conveyance of gaseous or liquid substances and influences the degree of miniaturization.

15       In a preferred version, the connecting ducts (208, 209) between the pumping chamber and the shut-off chambers are of straight design and have a ratio of the duct length to the respective hydraulic diameter of the ducts of at most 20, preferably at most 10, particularly preferably at most 5.

20       A further particularly preferred form of the diaphragm pump or of the pump head is characterized in that the connecting ducts and portions of the inlet and the outlet ducts are at an angle  $\alpha$  with respect to a line that is perpendicular to the plane of the face of the plate in which they are formed, the angle  $\alpha$  being in a range of +/- 20 to 70 degrees, preferably in the range of +/- 30 to 60 degrees (Fig. 3b). The angle  $\psi$  is  
25       measured from the deepest point of the depression to the connecting duct or inlet duct or outlet duct (Fig. 3b).

30       The ducts and duct portions which are at an angle reduce flow losses during the intake and the conveying operation. A pressure-loss reduction is particularly advantageous, because flow processes in the diaphragm pump according to the invention or in the pump head are initiated by abruptly changing variations in

pressure and vacuum. In principle, this feature may also be applied to a diaphragm pump/pump head according to copending application Serial No. 10/383,954.

5 The small dead-space volume between the pumping and the shut-off chambers improves the intake capacity of the diaphragm pump or of the pump head.

A further particularly preferred form of the diaphragm pump/pump head is characterized in that the pump head is comprised of at least three plates and at least one outer plate is designed to be thermally controllable. In principle, this feature may  
10 also be applied to a diaphragm pump/pump head according to copending application Serial No. 10/383,954.

The thermal control of the outer plate takes place by thermostat control or by electrical heating combined with a cooling device.

15 The present invention preferably relates, moreover, to a diaphragm pump with controllable valves and with a decentral control unit, characterized in that in the pump head, in the throughflow direction of the fluid, the inlet duct with a throughflow shut-off chamber and with connecting duct to the pumping chamber has  
20 a larger hydraulic cross section than the discharging connecting duct with a following shut-off chamber and outlet duct.

The present invention relates particularly preferably to a diaphragm pump with controllable valves and with a decentral control unit, characterized in that, in the  
25 pump head, the volume of the pumping chamber (211) is in the range of 0.005 ml to lower than 1000 ml, preferably 0.01 ml to 100 ml, and, particularly preferably, the volume of the pumping chamber is 0.1 ml to 10 ml.

The present invention relates in a very particularly preferable way to a diaphragm  
30 pump with controllable valves and with a decentral control unit, characterized in that, in the pump head, the dead-space volume of the product space of the pumping

chamber (211) is 0,1% to 20%, preferably 0,1% to 10% and particularly preferably 0,1% to 5%.

5 An increase of the performance by combining in a compact style for example two pump heads with controllable valves and with a decentral control unit, comprised of three plates, and depressions located in the parting planes of the plates and having common inlet and outlet ducts and angled connecting ducts between the pumping and shut-off chambers is possible if in the middle plate, one pumping depression (303, 303') and at least two shut-off chambers (301, 305) are introduced on each side, and 10 the inlet duct issues in the intaking throughflow direction onto a connecting duct which connects two shut-off chambers (301, 301'), and, in a discharging flow direction, the connecting duct likewise connects two shut-off chambers, and, via the outlet duct, a feed material can emerge from the pump head, and, in conjunction with the decentral control, the actuation of all the pumping and shut-off chambers is 15 linked in such a way that the function of a double diaphragm pump with controllable valves is fulfilled (Fig. 3a).

The shut-off chambers assigned in each case to a pumping chamber must in this case be activated with a time offset in the control sequence, so that the pulsations which 20 arise are halved.

The three plates of this diaphragm pump according to Fig. 3a are preferably releasably connected to one another for cleaning and repair purposes.

25 A further preferred form of the diaphragm pump is characterized in that the pump is comprised of at least three plates and at least one pumping chamber is provided in the middle plate (Fig. 4 or Fig. 4a), and at least three smaller shut-off chambers belong to each pumping chamber and each shut-off chamber possesses a connecting duct to the pumping chamber and an inlet duct or outlet duct for the supply or discharge of at least one fluid, and all the chambers can be activated separately via a decentral 30 control unit.

A diaphragm pump for example consisting of a pump chamber with at least three shut-off chambers allows the sequential or alternating conveyance of at least two different fluids. Thus, for example, two different substances can be supplied to a process by means of one pump, in which case the stroke ratio of the feed substances may be identical or different.

The benefits to the user are that, with one metering unit, at a low outlay in terms of investment and of assembly, and also with the least possible amount of space required, a plurality of substances can be supplied in a desired ratio to a process by means of one pumping unit. Particularly in applications in the pharmaceutical sector where low dead-space volumes and a sterilizability of the technical components used are required, it is particularly advantageous to employ the diaphragm pump according to the invention.

In an alternative embodiment, the diaphragm pump according to the invention or the pump head according to the invention is used as a conveying device. In this case, the diaphragm pump according to the invention or the pump head according to the invention is suitable for a sampling of liquids or gases from closed appliances.

Fig. 7 illustrates by way of example a pump circuit for sampling and sample preparation. Two diaphragm pumps (700, 700') equipped with a middle plate (400, 400') according to Fig. 4 are combined with a mixing chamber (701), so that all the functional parts are introduced in the three, albeit enlarged, pump plates. The diaphragm pumps have a pumping chamber (702, 702') and each pumping chamber has four associated shut-off chambers (703, 704, 705, 706 and 703', 704', 705', 706'). The shut-off chambers are assigned in each case inlet ducts and outlet ducts (identified by flow arrows in the figure). Figure 7 illustrates all components for automated sampling with subsequent processing and transport away to a connected analyzer. An illustration of the control unit for the separate activation of the chambers and a sectional illustration of the three plates have been dispensed with.

It can be seen from Fig. 7 that a substance sample can be sucked up when the inlet duct (707) and the outlet duct (708) are connected to a reactor. A substance quantity can be constantly pumped around from the reaction vessel via the inlet duct (707), intake valve (704), pumping chamber (702), delivery valve (705) and outlet duct (708) of the pump (700). The control, for example, changes over at a desired time, so that the delivery valve (705) closes and the valve (706) opens and a defined substance quantity is transferred through the outlet duct of the valve (706) into the mixing chamber (701) by means of the known pumping-chamber volume. As soon as the sample is transferred, the pump (700') starts in order likewise to generate pumping-around circulation to the mixing chamber. In this case, the inlet duct of the valve (704') and the outlet duct of the valve (705') are connected to the mixing chamber. Then, in parallel with the operative pumping-around circulation of the mixing chamber, the pump (700) can, via the inlet duct (709) and the valve (703), with the valve (704) closed at the same time, convey into the mixing chamber an additional diluting agent which is mixed with the substance sample there. After the mixing process by means of the pump (700'), the diluted substance sample is conveyed to a possible analyzer. In this case, the valve (705') closes and the valve (706') opens. By virtue of the sum of all the supplying pump strokes to the mixing chamber, with the same number of strokes the prepared sample can be transferred out via the outlet duct (710) and, if appropriate, conveyed for analysis. Furthermore, the inlet duct (709) is extended as far as the valve (703'), so that, after the sample transport, the second pump can also be scavenged by diluting agent when corresponding valves are switched.

The conveying device has a low dead-space volume.

This low dead-space volume is necessary so that the deposition and ageing of extracted substances do not falsify the analysis result due to old substances which otherwise clog the product-receiving ducts, and high operational availability is afforded.

The conveying device according to the invention allows exact sampling and a near-user volumetric conveyance of liquids, gases or liquefied compressed gases. It is particularly advantageous for these purposes because the stroke volume of the pump head can easily be adapted to operational requirements.

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The diaphragm pump/conveying device according to the invention is operated by means of a decentral electropneumatic control unit.

10 However, a decentral electropneumatic control unit, as in Fig. 1, also allows a synchronous activation of a plurality of pump heads. The parallel operation of the plurality of pump heads by means of only one control unit allows the efficient use of the diaphragm pump/conveying device according to the invention, for example, in decanting systems of all decanting appliances. The invention therefore also relates to decanting systems or decanting appliances which contain at least one diaphragm  
15 pump according to the invention.

A decentral electropneumatic control unit also permits a time-offset activation of individual pump heads, so that, when a plurality of pumps are operating in parallel, reduced pulsation occurs.

20 By means of the diaphragm pump according to the invention with a decentral electropneumatic control unit and with an adjustable disc in the control space of the pumping chamber, efficient use, at the same time with low investment costs, is possible. This becomes particularly clear when changing tasks demand conveying streams of different size which cannot be covered by one type of pump head. In the  
25 case of conveying streams of different size, only the pump head has to be exchanged, while the control part remains unchanged. The exchange of the pump head takes place simply by the unclamping of the pneumatic control lines.

30 The control for conveyance by means of the diaphragm pump is preferably carried out in such a way that a conveying stroke consists of at least four individual successive control steps and each individual control step is separated from the

following control step by means of an intermediate or associated constant or variable time element, and the delivery or the metering capacity of the pump can be varied by the variation of at least one time element.

5       The time elements interposed between the control steps ensure that the pneumatically triggered part-steps of the pumping stroke are carried out exactly and fully and the individual steps take place reproducibly. The synchronous variation of all the time elements for regulating the delivery capacity ensures a simple operator-friendly handling of the pump.

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The time elements T belonging to the control amount preferably to 0.001 seconds to 100 seconds, preferably the range is between 0.03 seconds and 30 seconds, and, particularly preferably, the time element amounts to 0.03 seconds to 10 seconds.

15       The time elements ensure that the high-speed electronic control signals (signal transit time), the slower pneumatic operations for deflecting the diaphragms and consequently the hydraulic displacement operations on the product-touched side of the diaphragm are not discontinued prematurely. Particularly when viscous substances with a viscosity of 0.1 mPas to 5000 mPas are being conveyed, the fluid-  
20       dynamic operations require more time than the electronically triggered signals of the control.

The metering cycle preferably consists of at least four control steps and has at least two different time elements, of which only one time element is variable and is used  
25       for regulating the pumping cycle.

For the time optimization of the pumping cycle of a diaphragm pump according to the invention, the pneumatic opening and closing operations of the diaphragms in the shut-off chambers may be provided with a non-adjustable smaller time element and a  
30       variable time element may be used for the OPEN/SHUT switching of the middle larger pumping chamber.

Two different time elements are advantageous particularly when the volume of the shut-off chambers is smaller than the volume of the pumping chamber.

5 Particularly on the basis of the electropneumatic control and the changing pneumatic states in the control lines and control spaces of the diaphragm pump, between the vacuum or a pressureless state of the opening operation and an increased pressure of the closing operation of the chambers, it is advantageous to operate with different time elements and thus increase the performance of the pump.

10 In a particularly preferred operating mode, each time element is larger than the required switching time of the associated electropneumatic multi-way valves in the control unit.

15 In a particular version of the control, the associated time element for the diaphragms of the shut-off chambers is 0,01 to 0.15 seconds and preferably 0,01 to 0.075 seconds and particularly preferably 0,01 to 0.05 seconds.

Preferably at least two diaphragm pumps are connected in parallel to the electronic and the electropneumatic control unit.

20 An electropneumatic control unit can activate a plurality of diaphragm pumps in parallel, so that the pumps can synchronously meter different substances in different quantities simultaneously by means of pumping chambers which, if appropriate, are of different sizes.

25 The thickness of the elastic diaphragm is preferably larger than 0.1 mm and smaller than 5 mm and the height of the pumping and shut-off chamber in the region of the vertex of the chamber (greatest extent across the diaphragm) is particularly smaller than 10 times the diaphragm thickness.

30 Materials such as plastics and elastic diaphragms undergo dilation and permanent deformation under stress. This permanent or plastic deformation has direct effects on

metering accuracy, in particular in relation to the individual metering stroke. For precision metering using diaphragm technology it was found in tests that the movement of the diaphragm and thus the height of the shut-off chambers and pumping chambers cannot be of unlimited desired magnitude.

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In course of the present invention it was surprisingly found that, starting from the fixed, non-stressed diaphragm state up to the maximum stressed diaphragm state narrow limits have to be observed between the plates in order to allow the exact metering of the liquid concerned.

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In the case of a pumping chamber geometry such as for example in the shape of a spatial spherical segment, the maximum diaphragm dilation or deformation is determined by measuring the change in length between the chord length and the arc length of a spherical segment. The diaphragm is not stressed at the level of the chord of the spherical segment and is stressed at the level of the arc length of the spherical segment. Based on the chord and arc length of the spherical segment, the width and the maximum height of the spherical segment and thus the volume of the pumping chambers and shut-off chambers can be mathematically determined (cf. Fig. 8). This method of determination can be applied analogously to other pumping chamber and shut-off chamber geometries.

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The maximum deformation of the diaphragm into the larger product-side depression must be no more than 20%, preferably no more than 10%, and more preferably the deformation should be less than 5%, in order to obtain consistent high diaphragm movement and high metering accuracy, and in particular short-time accuracy.

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The diaphragm deformation limits identified therefore determine the heights of the shut-off chambers and pumping chambers formed by the diaphragms, so that the metering accuracy of the diaphragm pump according to the invention is improved considerably.

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The concave depressions in the plates may have various geometric shapes, such as, for example, that of a cylinder, of a spherical segment or of a cone frustum.

5 The diaphragm pump or the pump head preferably has smaller depressions for the suction-side and delivery-side shut-off chamber than for the pumping chamber, and all the depressions are arranged completely on the product side of the diaphragm side in the middle plates.

10 A variant of the diaphragm pump or of the pump head is preferably comprised of a pneumatically controlled pumping chamber combined with two magnetically operated valves as shut-off chambers.

15 The diaphragms used in the diaphragm pump or in the pump head are preferably designed to be larger in diameter than the diameter which is formed by the chambers in the parting plane of the plates, and the diaphragm diameter is particularly preferably at least 20% larger.

20 In a further alternatively preferred embodiment, metallic diaphragms are used as a pumping diaphragm and are introduced or are connected unreleaseably to one of the plates, in particular an outer plate, by welding.

25 In a further particular embodiment, a pulsation damper is mounted downstream of the delivery-side shut-off chamber in the direction of flow, particularly in the region of the outlet duct of the diaphragm pump or of the pump head.

30 In a further particular embodiment, the diaphragm pump or the pump head is equipped with an integrated spring-loaded overflow valve, in order to generate internal product circulation in the pump head. If the connected control pressure is higher than the desired pump pressure, an integrated possibility of expansion from the pump delivery side to the pump suction side is provided.

In a further particularly preferred version, at least two pump units, comprised of two pumping chambers with four associated shut-off chambers, are arranged next to one another in the three rigid plates so as to form a pump set.

5       The subject of the invention is also a pump set comprised of two or more diaphragm pumps, the diaphragm pumps according to the invention having a common control unit.

A pump set in which the pump heads have common continuous plates is preferred.

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In a preferred embodiment, the present invention relates to a diaphragm pump which is used as a controllable multi-duct diaphragm valve consisting of three plates, characterized in that a distributor chamber is connected to an inlet duct via a connecting duct having at least one shut-off chamber which has an outlet duct, and  
15       the chambers have depressions of identical size and can be activated separately, so that, for the passage of a material, at least two chambers must be opened simultaneously in the desired throughflow direction, and all the chambers are actuated by a decentral electropneumatic control unit.

20       The diaphragm pump according to the invention is suitable as a multi-duct diaphragm valve particularly for the uniform distribution of liquids and gases to a multiplicity of consumers, since it has a compact form of construction, the smallest possible dead spaces and, by virtue of the small control spaces, short switching times to pass from the OPEN position into the SHUT position.

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With the inlet duct of the distributor chamber closed, the diaphragm pump according to the invention, as a multi-duct distributor valve, can be used as a distributor valve in order to guide two different liquids to a multiplicity of offtake points of the distributor valve. In this case, for example, at least two shut-off chambers are  
30       connected to different fluid supplies, so that distribution is possible via the central distributor chamber to a multiplicity of, but at least more than two, shut-off chambers with associated outlet ducts. In this case, three chambers are opened for sequential

fluid passage. In the state of rest, at least two chambers of the multi-duct distributor valve are closed (Fig. 6a ).

5 When the diaphragm pump according to the invention is used as a multi-duct distributor valve for the distribution of at least two different fluids to a plurality of consumers, reference may also be made to transmitting and dispensing shut-off chambers.

10 This ensures that, in the state of rest, there is an additional safety shut-off between a plurality of separate transmission ducts and a plurality of separate reception ducts.

In the diaphragm pump itself or in case that the diaphragm pump is used as a multi-duct distributor valve, the actuation of the diaphragms into the OPEN or SHUT position may take place pneumatically, electrically or by means of a hydraulic fluid.

15 By means of the diaphragm pump according to the invention with an activatable intake and delivery valve or an intake-side and a delivery-side shut-off chamber, very small volume flows of  $<5 \mu\text{l/stroke}$ , but also higher volume flows into the ml range per stroke, can be conveyed in a reproducible way, depending on the design size. The separate set-up between the actual pump unit or pump head and the decentral electrical or electropneumatic control unit is particularly advantageous. As a result, the amount of space required for a continuously operating conveying apparatus in, for example, a high miniaturization test installation for screening work is very small. This pump principle works without mechanical gearing, and the required structural parts of the pump head have no dynamic function, with the exception of the deflection of the diaphragm in the region of the shut-off and the pumping chamber. Thus, even for a miniaturized version of the pump components, there is no need for precision manufacture. Owing to the absence of mechanical parts, there are no mechanical disturbing influences, and the manufacturing costs for this reproducibly operating diaphragm-pump head are minimized considerably. The pump requires merely a power and a compressed-air supply so as to be capable of working; these are present, for example, in any laboratory.

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It is particularly advantageous to use the diaphragm pump for the metering of very small quantities of liquid substances, of which the volume per pumping stroke lies appreciably below the specific drop size. By the pneumatic conveying energy being applied to the control side of the displacement diaphragm of the pumping chamber quickly, the intake product volume in the pumping chamber is thrown out of the product space of the chamber and to the outlet duct and no drop is formed at the discharge point of the pump. As a result, a metering of small liquid quantities into a reaction mixture is not delayed in time and a synthesis process is started synchronously with the metering.

The metering of small quantities of substances against a pressure applied in the opposite direction can be carried out very effectively, since the diaphragms of the shut-off chambers and the pumping chamber are elastic and close the supplying and discharging product ducts in a gas-tight manner when the chambers are in the SHUT position, so that no material is forced back onto the inlet side of the pump via the outlet side of the pump head by means, for example, of the gas phase of a connected pressure vessel, and intake under normal pressure is not interrupted.

A further advantage, as compared with the prior art, is that, by virtue of the small dead space and the leak-tight shut-off and pumping chamber, a sensitive product to be metered is supplied to the intended location without a long dwell time and remixing.

Advantages are afforded particularly in comparison with microstructure technology. Since the duct dimensions are large in relation to the metering volume, the pump is relatively insensitive to contamination. A fault which is caused by a product impurity and becomes noticeable due to an increasing metering error or which may lead to the failure of the metering of the pump is greatly reduced on account of the large product ducts. Product impurities can be flushed through the relatively large product ducts during the metering.

The extremely low hold-up of the pump head and the small dead-space volume ensure a good intake behavior and a rapid reproducible metering, particularly in applications relating to new pharmaceutical materials which are available only in small quantities at the early development stage.

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The establishment of small streams of liquid is particularly simple, because the setting of the metering quantity, along with a constant displacement volume, takes place by means of an interposed time element in the control. Volume flows can thereby be varied in a very simple way without cross-checking. The variation in the metering capacity of a diaphragm-pump head is carried out by the metering stroke being shifted on a time axis.

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The lamella-like construction of the diaphragm pump with integrated controllable valves, which generates a pulsating metering stream by virtue of the pumping principle, makes it possible to equalize the metering stream by a multiplication of the displacement unit and of the valves, the structural dimensions of the pump in the test installation not being increased appreciably.

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Further design variants for the mobile use of the diaphragm pump according to the invention are possible when the controllable valves are replaced by electromagnetically controlled valves (supply voltage, for example, 6 for 12 volts). In mobile uses, the control unit can then be supplied with power via a battery, so that the control unit remains operative for a long time. The pneumatically operated working diaphragm for the conveyance of liquid substances may be supplied with a portable compressed-air accumulator which, for reasons of weight, may be made, for example, from plastic. The diaphragm pump according to the invention, the pumping chamber of which has a small control-space volume, can be operated for a long time via the compressed-air accumulator. The inventive diaphragm pump is appropriate for mobile uses, for example in the discharge of plant protection agents in difficult terrain.

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Further operational benefits for the user are afforded in that the wearing parts which come into contact with product can be replaced simply and cost-effectively.

#### Brief description of the drawings

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The invention is explained in more detail below, by way of example, with reference to the figures.

10 Fig. 1 shows the diagrammatic set-up of a pneumatic diaphragm pump of lamella-like construction, with an associated electropneumatic control unit and a programmable electronic control and with connecting lines.

Fig.2 shows a sectional illustration of a pump head with an externally variable wall in the control space of the pumping chamber.

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Figs. 2a, 2b show various design contours of the variable control-space wall (axially movable disc).

20 Fig. 3 shows a chambered pump diaphragm.

Fig. 3a is a sectional illustration, the middle plate having two pumping chambers and associated shut-off chambers and the outer plates being equipped with a variable control-space wall (axially movable disc).

25 Fig. 3b shows a diagrammatic pump head with oblique ducts.

Fig. 4, 4a show the middle plate of a diaphragm-pump head with a plurality of shut-off chambers and a plurality of inlet and outlet ducts.

30 Fig. 4b shows diagrammatically a diaphragm-pump head with a central pumping chamber and with a plurality of shut-off chambers and associated inlet and outlet ducts.

- Fig. 5 shows a multi-way diaphragm distributor valve in a sectional illustration.
- Fig. 6 is a diagrammatic illustration of a multi-way distributor valve.
- 5 Fig.6a illustrates diagrammatically a multicomponent distributor valve.
- Fig. 7 shows an integrated sampling system with two diaphragm pumps.
- 10 Fig. 8 shows schematically the two-dimensional area of a spherical segment having different diaphragm deformation states.

## **Examples**

### **Example 1**

5 Figure 1 illustrates a diaphragm pump with a pump head (200) in cross section, with an associated control (100) and casing and a pneumatic distributor (115). In the pump head according to Fig. 1, a movable disc (1001) a firmly connected rod has been inserted to allow a manual adjustment of the movable disc. Electronic components and a freely programmable electrical control are installed in the casing. A power supply line, not illustrated, serves for the voltage supply of the electronic components. The casing has a display (101), an on/off switch (102) and a plurality of function keys (103 to 109), by means of which required parameters for the pumping sequence or for the pumping operation can be entered, tracked visually and stored. The electronic control (100) allows various operating variants, so that a switch can be made to the continuous operation of the pump by means of the key (103) and to the discontinuous operation of the pump by means of the key (104). In particular, the discontinuous operation of the pump can be set by means of a preselectable number of pump strokes and be stored in the control by means of the key (105). A reduction in the set parameters is obtained by means of the key (106), and the key (107) is provided for increasing the variable parameters which can then be stored, likewise by means of the key (105), in the control as newly selected operating parameters of the diaphragm pump. In the continuous operating mode, the time constants can be varied by means of the keys (106, 107). The key (108) makes it possible to choose between internal and external control, for example by an external process management system. The pump head (200) starts to operate when the key (109) is actuated and, with the repeated pressing of the key (109), the operation is stopped again. The electronics together with the programmable control transmit, at the start of the metering, via electrical connecting cables (110), digital signals to the electropneumatic multi-way valves (111, 112, 113, 114), which are then switched into their defined open or shut position (Table 1). The electropneumatic multi-way valves (111 to 114) are mounted on a pneumatic distributor block (115). The distributor block has two supply ducts (116, 117). The supply duct (116) is connected

directly to the compressed-air supply and the distributor duct (117) is connected to the vacuum supply by means of a vacuum line. The vacuum is generated by the vacuum generator (118), an injector, which is installed in the bypass and which is constantly supplied with compressed air by the valve (114) when the electrical control is switched on. In a compact form of construction, the distributor block (115), together with the electropneumatic 2/3-way valves and the vacuum generator (118), is located directly in the casing of the control (100), so that the compressed-air supply of the supply duct (116) is connected via a hose coupling (116') and the pump head is connected via the hose couplings (119', 120', 121'). The freely programmable electropneumatic components, diodes for the visual function indicator, electrical power pack and an electrical board are not illustrated in Fig. 1.

The freely programmable control of the pneumatically operated diaphragm pump with a pump head (200) switches the electropneumatic multi-way valves (111 to 114) and conducts the pneumatic pressure, prevailing the distributor block (115), in the duct (116) (delivery duct) or the vacuum in the distributor duct (117) (vacuum duct) through the control lines (capillaries or hoses) (119, 120, 121) to the pneumatic control spaces (pneumatic spaces) (220, 221, 222) into the pump head (200).

The valve (111) is connected to the intake valve (lower shut-off chamber (210) of the pump head (200) by means of the control line (119). According to the same diagram, the other valve (112) (upper shut-off chamber (212)) and the valve (113) are connected to the pumping chamber (211) of the pump head (200). The valve (114) supplies the vacuum generator constantly with compressed air and is switched immediately as soon as the electronics are supplied with electrical voltage.

The diaphragm-pump head (200) consists of the three part-plates (201, 203, 205) and has inserted elastic diaphragms (202, 204) which are pneumatically deformable in the region of the pumping chamber (211) and shut-off chambers (210, 212). The diaphragms (202, 204) are somewhat smaller than the plates (201, 203, 205), in order to ensure good sealing-off relative to the atmosphere. In the plate (203) are introduced depressions which form the pumping and shut-off chambers (210, 211, 212),

the respective compensating volume of the shut-off chambers (210, 212) being introduced in the plate (201). The pumping chamber (211) is incorporated with a smaller compensating-volume fraction in the plate (205) and with the larger pumping-volume fraction in the middle plate (203).

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The shut-off chamber (210) designates, for example, the controllable intake valve of the pump head. The pumping chamber (211) accordingly represents the conveying chamber and the shut-off chamber (212) presents the controllable delivery valve of the pump head.

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The diaphragms (202, 204) divide the pumping and shut-off chambers into control spaces (220, 221, 222) and into product spaces (230, 231, 232).

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The pumping and shut-off chambers (210, 211, 212) are in the form of spherical indentations. The middle plate (203) has an intake duct (207) and an outlet duct (206). The two ducts (206, 207) are extended in each case by a welded-in capillary. The ducts (209, 208) connect the product spaces (230, 231, 232) of the chambers (210, 211, 212) to one another.

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The pumping chamber (211) has a groove (213) as a connecting element from the lowest geometric point of the depression in the plate to the outlet orifice or to the connecting duct (209). It also becomes clear that, between the inlet duct (208) and the start of the outlet duct (209) with the connecting groove (213), there is still a sufficient distance to allow leak-tight closing of the orifices in the product space of the pumping chamber by the diaphragm (204).

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The pump head (200) is shown here in the control step 4 (see Table 1). In the region of the shut-off chamber (210) (controllable intake valve), the diaphragm (202) is acted upon by pressure on the control-space side (220), so that the diaphragm (202) blocks the intake duct (207) at the inlet (240) (Fig. 2) and the connecting duct (208) at the outlet (241) (Fig. 2). In the region of the pumping chamber (211) (conveying chamber or displacement unit), the associated control space (221) is acted upon by a

vacuum, so that the actively conveying diaphragm region lifts off and opens the supplying and discharging connecting duct (208, 209). The shut-off chamber (212) is likewise acted upon by a vacuum on the control side, so that the connecting duct (209) and the outlet duct (206) are opened, in order, in the following control step 5 (see Table 1) to displace the liquid volume out of the pumping chamber. It can be seen that the respective diaphragm movement extends over the entire height of the depression. Fig. 1 does not illustrate the screws necessary for drawing together the plates and at the same time pressing together the inserted diaphragms.

10 The order of the programmable control steps and the position of the valves (111 to 114) are illustrated below in Table 1. Digital signal "1" means that compressed air prevails (result: the diaphragm is pressed onto the plate (203) and closes) and the signal "0" means that a vacuum prevails (the diaphragm is raised in the control space and opens). As soon as the electronic control is supplied with electrical voltage and is  
15 switched on by means of the key (102), the programmed control switches the valves (111 to 114) into a defined starting or basic position. The control of a complete pump stroke consists here, for example, of five individual steps. When the pumping operating is interrupted or terminated, the control jumps into the starting or basic position.

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**Table 1**

Step	(111) Suction valve	(113) Displacer	(112) Pressure valve	(114) Vacuum
Basic position	1	1	1	1
1st step	0	1	1	1
2nd step	0	0	1	1
3rd step	1	0	1	1
4th step	1	0	0	1
5th step	1	1	0	1
		Back to Step 1		

In the control sequence, a variable time element is programmed and assigned (not  
5 illustrated in Table 1) for each control step 1-5, so that the individual control steps  
taking place in succession do not influence one another and are executed completely.  
The switching times of the electropneumatic valves are longer and therefore  
substantially slower than the time required for transmitting the digital signals. By  
means of the interposed time elements, the pumping function can be reproduced  
10 according to the control cycle 1-5 (see Table 1) and is performed completely.

**Example 2**

Fig. 2 shows a sectional illustration of a pump head (200) consisting of the plates  
15 (201, 203, 205). What can be seen are the elastic diaphragms (202, 204) clamped in  
the parting planes of the plates, and also the shut-off chamber and the pumping  
chamber with the associated depressions (spherical indentation) in the middle plate.  
The outer plate (205) is made thicker, so that the control space (221) is enlarged  
beyond the associated compensating volume. The control space is additionally  
20 widened by the amount of a smaller cylindrical depression (1000) and by the amount  
of a threaded bore which is led outwards. The enlarged control space has installed in  
it the stepped disc (1001) with a one-sided cylinder, a stepped threaded rod (1002)

led through the outer plate being fastened in the said disc, so that, in the event of even only a slight rotation of the outer knurled nut (1003) fastened on the threaded rod (1002), the disc (1001) is axially moved or displaced in the control space. The threaded rod is stepped and is fastened releasably to the receiving cylinder of the disc by means of two pins (1004). A seal (1005) is positioned on the one-sided cylinder, located in the control space, of the disc, in order to seal outwardly the control space acted upon by pneumatic pressure. The disc (1001) is provided with a plurality of bores (1007) and with a concentrically raised ring (1008), in order to assist the action of pressure upon the entire control space and to prevent the closing of the bore (1006) in the event of the complete return of the disc. The supply of compressed air or action by means of a vacuum takes places via the laterally offset bore (1006). In Fig. 2, the adjustable disc has the contour of a spherical segment and is consequently adapted to the contour of the process-side depression.

If the threaded rod is provided, for example, with a fine-pitch thread, the disc (1001) can be displaced axially in the event of even only slight manual rotation of the knurled nut (1003) and the diaphragm travel, which at the same time determines the liquid volume to be conveyed, can thereby be varied.

Fig. 2a and Fig. 2b show further design variants, in particular different contours of the movable disc. The diaphragm-side contour of the disc (1001') in Fig. 2a is plane, while the contour of the disc (1001'') in Fig. 2b exhibits an obtuse cone. Furthermore, the two figures show that the disc can be manufactured with a one-sided cylinder and with a directly worked-on threaded rod, in order as far as possible to reduce the number of components, the costs and the assembly work.

### **Example 3**

Figure 3 shows by way of example the chambering of a pumping diaphragm (204) in a sectional illustration. In the upper part of the figure, the chambered diaphragm (204) is not in the operating state, while, in the lower part of the figure, the control space (221) of the diaphragm (204') is acted upon by pressure and the deflection of

the diaphragm occurs. It can also be seen that the diaphragm is clamped between the plates (203, 205) and parts of the connecting ducts (208, 209) are present in the plate (203). The pumping diaphragm is clamped between the plates in the outer region, while the diaphragm is open in the center, so that chamber elements (1100, 1101) can be fastened on both sides. The chamber elements have, towards the elastic diaphragm, a raised rounded concentric outer ring (1102, 1103), so that the enclosed diaphragm surface is no longer subjected to force while the chamber elements are being screwed together.

It is advantageous if the contour of the process-side chamber element (1104) is adapted to the depression contour, so that the dead-space volume of the pumping chamber is not appreciably increased. If the product-side chamber element is provided or coated with an elastic film (1105), the connecting ducts can be closed in a leak-tight manner in the loaded diaphragm state. In Fig. 3, it can be seen that, in the event of plastic deformation of an elastomer, the degree of deformation due to the slight deflection, which is to be seen as a function of the diaphragm diameter, is negligible. The chamber elements also afford the possibility of using diaphragm materials which would be less suitable on account of the high permanent deformation.

Fig. 3b illustrates diagrammatically a diaphragm pump consisting of three plates (201, 203, 205), and it can be seen, in particular, that connecting ducts (208, 209) and portions of the supply and outlet duct (207, 206) are at an angle  $\alpha$ , so that no great pressure losses occur during rapidly changing flow states.

#### **Example 4**

Fig. 3a shows a double diaphragm pump with controllable valves, which consists of three plates, and all the pumping and shut-off chambers have been introduced in the middle plate. It can be seen that the inlet duct (300) has a T-shaped configuration and connects the left-hand and right-hand intake-side shut-off chambers (301, 301'), so

that the two shut-off chambers have a common inlet duct. An angled connecting duct (302, 302') runs from each shut-off chamber to the pumping chamber (303, 303'). The downstream outflow region of the double diaphragm pump is configured almost mirror-symmetrically to the inflow region. The connecting ducts (304, 304') connect the pumping chamber (303, 303') to the shut-off chambers (305, 305') on the outlet side, and the shut-off chambers of the outlet side are connected to a common outlet duct (306). In this example, a double diaphragm pump is described, with a split inner passage duct. In this example, the double diaphragm pump is equipped with a movable disc (1001) for possible part-stroke operation. No releasable connecting elements of the plates are shown in Fig. 3a, and the pump head is not in an operating state. The throughflow direction of the double diaphragm pump is indicated by arrows.

#### **Example 5**

Figs. 4, 4a show front views of a middle plate (plate 400), in which four shut-off chambers (1200, 1201, 1202, 1203) are assigned to a pumping chamber (1205). The chambers are formed by depressions in the shape of a spherical segment (spherical indentation). Each shut-off chamber has a connecting duct (1206) to the central pumping chamber (1205), and, in addition, in each case two shut-off chambers are provided with a separate inlet duct (1207, 1208) and two shut-off chambers are provided with a separate outlet duct (1209, 1210). In this exemplary embodiment, two different substances can be conveyed sequentially or alternately by means of one pump head. In an application for pharmaceutical purposes, the second inlet duct could also be used to pump a cleaning liquid and to initiate a scavenging operation. There is an alternative use for the second inlet duct when a steam connection is made and a sterilizing operation could thereby be initiated at any time. Thus, for example, the inlet duct (1207) may be connected to a supply line for a substance to be metered. During the intake operation, the substance passes into the pumping chamber (1205), in order then to be forced through the shut-off chamber (1202) into the outlet duct (1209). A sterilizing operation requires a steam connection on the inlet duct (1208). The steam could pass through the shut-off chamber (1201) into the pumping chamber

1205), in order subsequently to pass through a connecting duct to the shut-off chamber (1203) and to the outlet duct (1210). In the pharmaceutical field of use, metering or pumping operations and sterilizing steps take place sequentially, so that, by virtue of a separate activatability of the pumping chamber and shut-off chambers, the outlay in terms of automation is low. Fig. 4 shows an angled connecting groove (1215) in the pumping chamber (1205) and bores (1216) for receiving ties or releaseable fastening elements, by means of which all three plates can be fastened. Fig. 4 clearly shows the pumping chamber, connecting ducts (for example 1206) and a groove (1215) for better product discharge from the pumping chamber. Fig. 4a clearly shows the shut-off chambers with inlet and outlet orifices.

A chamber circuit is illustrated diagrammatically by way of example in Fig. 4b, a pumping chamber (1205) and six shut-off chambers (for example 1200), illustrated in the figure as a circle, and also associated inlet ducts (1207, 1208, 1213) and outlet ducts (1209, 1210, 1214) being interlinked. By virtue of the separate activation of each individual chamber, a plurality of different fluid streams can be connected sequentially or alternately to all the existing outlet ducts via a common pumping chamber (1205).

It can be seen from Figs 4, 4a and 4b that a pumping chamber with more than three shut-off chambers and with the corresponding inlet and outlet ducts can be used for an automated sampling system. Thus, for example, bypass pump-around circulation can be generated from a reactor or a product-carrying pipeline via the inlet duct (1207) which the shut-off chamber of the pumping chamber (1205) and the outlet ducts (1209). If a substance sample from the reactor is desired at a specific time, for example, the outlet duct (1209) closes and the outlet duct (1210) opens, so that a sufficiently large substance quantity can be extracted as a sample via the pumping chamber (1205). After the sampling, the pumping chamber is cleaned by means of an inert scavenging agent via the inlet duct (1208), in which case the cleaning liquid can be discharged separately via the outlet duct (1214). The inlet duct (1213) is provided, for example for a final sterilizing operation after the termination of the reaction.

### **Example 6**

Fig. 5 illustrates a multi-way distributor valve consisting of three plates and analogous to the pump construction. It can be seen, furthermore, that elastic diaphragms (1303, 1304) are clamped between the plates (1300, 1301, 1302) and thereby divide introduced depressions in the middle plate into a product space and a control space. In this illustration, the control spaces of the chambers are not widened, so that the diaphragms bear on the outer plates in a leak-tight manner in the parting region. Pneumatic connections (1305, 1306, 1307) through the outer plates (1300, 1302) are indicated by double arrows. The distributor valve is illustrated in the open state, so that, for example, the elastic diaphragms would be deflected by an applied pneumatic pressure and would thereby close the connecting ducts. When the pneumatic pressure is released, the connecting ducts in the product chambers are opened, so that a fluid can flow through. Fig. 5 shows a multi-way distributor valve which has a central inlet duct (1308) in the outer plate (1300), followed by a connecting duct (1309) to the distributor space (1310). The distributor space has two connecting ducts (1311, 1312) to smaller shut-off chambers (1313, 1314) which, in turn, have outlet ducts (1315, 1316) for the fluid discharge. It can be seen that, for example, a connected electropneumatic control unit must activate at least two chambers in order to release a switching travel for the passage of a material. In this example, the multi-way distributor valve or the distributor valve can guide a supplied material selectively to the left-hand outlet duct (1315) or to the right-hand outlet duct (1316). For cleaning purposes, the two outlet ducts can be opened simultaneously, so that parallel distribution is possible. The electropneumatic control unit does not require a vacuum generator, because, as a rule, fluid supplies have an initial pressure.

In the parting plane of the plates (1301, 1302), the connecting ducts are worked on one side into the surface of the plate (1301), so that all the connecting ducts are sealed off relative to one another and outwardly simultaneously by means of the inserted large-area diaphragm. Multi-way distributor valves are therefore preferably provided with full-area elastic films in the parting planes of the plates, in order to

achieve simpler assembly and, where cleaning is concerned, to simplify the operations. Due to the central supply of a material which is to be distributed, a circular orifice is provided in the elastic film (1303), so that the inlet duct (1308) and the connecting duct (1309) have a through-flow connection.

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The distributor chamber and the shut-off chamber can be activated pneumatically, for example by means of compressed air, or hydraulically by means of fluid. However, electromagnetic drives may also be used. The plates of the multi-way distributor valve are connected releaseably to one another.

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Fig. 6 illustrates diagrammatically the middle plate of a multi-way distributor valve. What can be seen is a central material inlet duct (1308') with a distributor chamber (1310') and with a multiplicity of connecting ducts (1312') having associated shut-off chambers (1314') and following outlet ducts (1316'). With this version, for example, a fluid can be conducted sequentially or in parallel to a multiplicity of consumers, in which case two chambers must always be switched into an open state.

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When the central inlet duct (1308') is closed, as shown in Fig. 6a, and, for example, two outlet ducts (1400, 1401) are converted to inlet ducts and connected to different material suppliers, there is a possibility of guiding these two materials in series to each connected outlet duct when two shut-off chambers and the distributor chamber are switched in the open state.

### **Example 7**

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Fig. 7 illustrates by way of example a pump circuit for sampling and sample preparation. Two diaphragm pumps (700, 700') are designed with a middle plate (400, 400') according to Fig. 4 and combined with a mixing chamber (701) so that all the functional parts are introduced in three, albeit enlarged, pump plates. The diaphragm pumps have a pumping chamber (702, 702'), and each pumping chamber has four associated shut-off chambers (703, 704, 705, 706 and 703' 704' 705' 706'). The shut-off chambers are assigned in each case inlet ducts and outlet ducts

(identified by flow arrows in the Fig.). Figure 7 illustrates all the components for automated sampling with subsequent processing and transport away to a connected analyzer. An illustration of the control unit for the separate activation of the chambers has been dispensed with.

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It can be seen from Fig. 7 that a substance sample can be sucked in when the inlet duct (707) and outlet duct (708) are connected to a reactor. A substance quantity can be constantly pumped around from the reaction vessel via the inlet duct (707), intake valve (704), pumping chamber (702), delivery valve (705) and outlet duct (708). The control, for example, changes over at a desired time, so that the delivery valve (705) closes and the valve (706) opens, and a defined substance quantity is transferred through the outlet duct of the valve (706) into the mixing chamber (701) by means of the known pumping-chamber volume. As soon as the sample is transferred, the pump (700') starts, in order likewise to generate pump-around circulation to the mixing chamber. In this case, the inlet duct of the valve (704') and the outlet duct of the valve (705') are connected to the mixing chamber. Then, in parallel with the operative pump-around circulation of the mixing chamber, the pump (700) can, via the inlet duct (709) and the valve (703), with the valve (704) closed at the same time, convey into the mixing chamber an additional diluting agent which is mixed with the substance sample there. After the mixing process by means of the pump (700'), the diluted substance sample is conveyed to a possible analyzer. In this case, the valve (705') closes and the valve (706') opens. By means of the sum of all the supplying pump strokes to the mixing chamber, the prepared sample can be transferred out via the outlet duct (710) and, if appropriate, conveyed for analysis by means of the same number of strokes. Furthermore, the inlet duct (709) is extended as far as the valve (703') so that, after the sample transport, the second pump can also be scavenged by diluting agent when corresponding valves are switched.

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### **Example 8**

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Fig. 8 schematically shows two plates 800, 801, between which an elastic diaphragm 802 is fixed. In plate 800 the product-side pumping space 800' is shown and in plate

801 the control space 801' of the pumping chamber is indicated. According to the invention, the membrane movement or membrane deformation always takes place between the limiting wall of the control space and the limiting wall of the pumping chamber, so that the maximum movement of the diaphragm is predetermined by the contours of the chambers.

In addition, it can be seen that in the first stress mode, the diaphragm, which is fixed in the plates and pneumatically actuated (chord length 807), can be deformed up to the chamber height 804, whereupon it assumes the arc length 803.

In the second stress mode the diaphragm is dilated up to the chamber height 806 with an arc length of 805, so that the diaphragm is deformed to a considerably greater degree with regard to the chord length than in the first stress mode. Larger diaphragm deformations would produce creases, so that the individual conveying stroke and the displacement volume would be decreased by the creases which form. In addition, the formation of creases in the diaphragm prevents the tight sealing of the feed and discharge cuts in the pumping chambers and shut-off chambers.

This finding means that the pumping and shut-off chambers and the diaphragm dilation associated therewith have an effect on metering accuracy. Where the pumping chamber has optimum dimensions in an areal shape of a spherical segment having a diameter of about 114 mm and a height of the chamber of about 1.5 mm no permanent diaphragm deformation occurs. The calculated chord length is about 26 mm and the corresponding arc length are approximately 26.4 mm. As a result, no permanent deformation of the diaphragm occurs in this example.

In the second stress mode the diameter of the spherical segment is about 26 mm and having the same chord length like in the first alternative. But the arc length is increased up to about 35 mm. From these data a diaphragm extension of about 34.6% can be calculated leading to inaccuracies in the metering process.

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In practice the knurled nut (1001) at the disk (1002) is positioned in that way that there is no deformation of the diaphragm. During the pumping procedure the diaphragm deformation into the geometric room of the pumping chamber can be adjusted by turning the disk via the nut.